

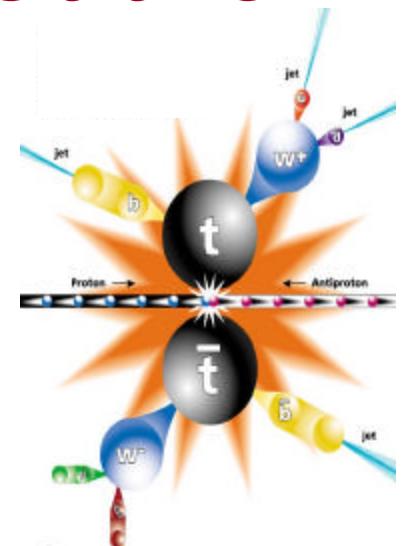
Top Quark Production Cross Section at the Tevatron.

Susana Cabrera

on behalf of the CDF and D0

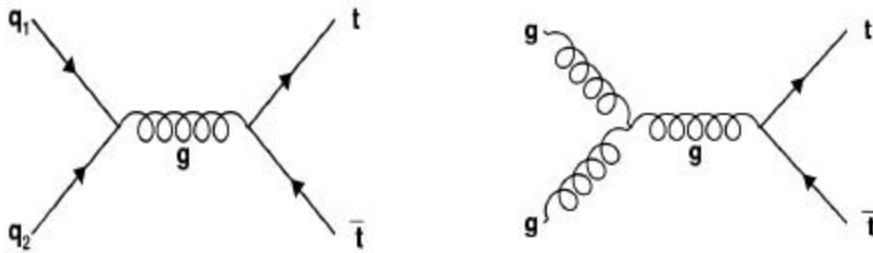
collaborations

Duke University



XXXVIIth Rencontres de Moriond
"QCD and High energy Hadronic
Interactions"

Pair production via strong interaction (dominant)

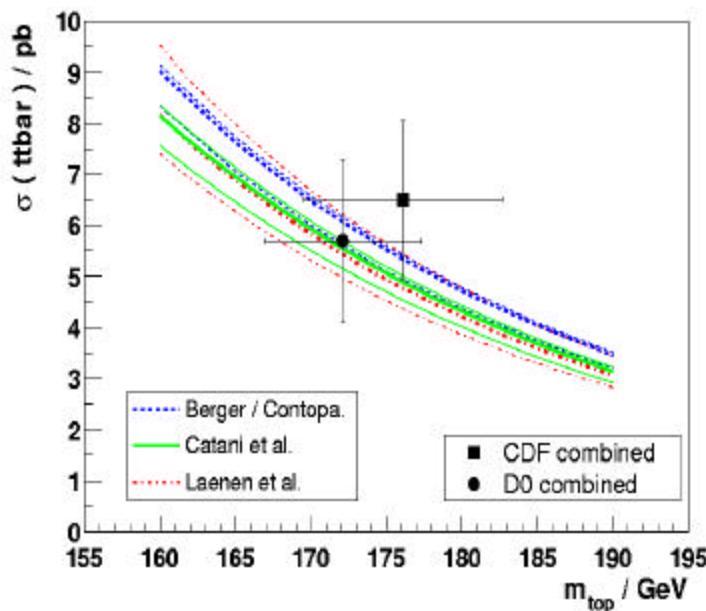


Single production via weak interaction (not yet observed)

$\mathbf{S}(t\bar{t})$ measurement is primarily
a “counting experiment”

$$\mathbf{S}(t\bar{t}) = \frac{N_{obs} - N_{bkg}}{A \cdot \int L}$$

Run 1 (110 pb^{-1}): $d\mathbf{S}(t\bar{t})/\mathbf{S}(t\bar{t}) \sim 26\%$



$$\mathbf{S}_{t\bar{t}}(\sqrt{s} = 1.96 \text{ TeV}) \approx 1.30 \times \mathbf{S}_{t\bar{t}}(\sqrt{s} = 1.8 \text{ TeV})$$

$\text{BR}(t \rightarrow W b) @ 100\% \rightarrow 3 \text{ main experimental signatures}$

- Dilepton (2 high- P_T leptons, 2 b jets, large E_T):

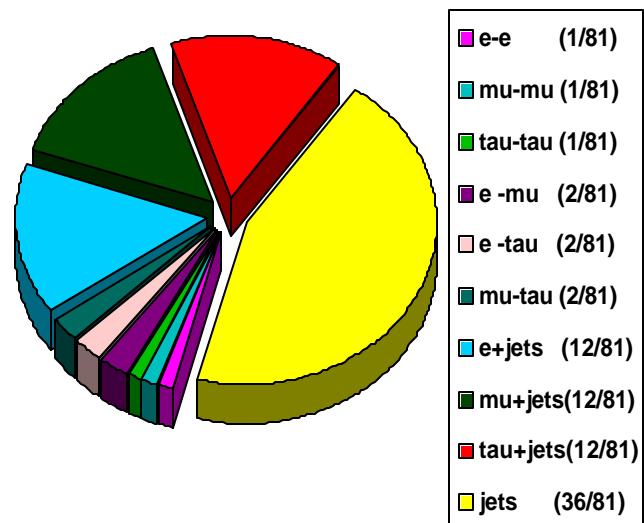
$$\text{BR} = 1/9 \quad \text{BR}(ee, \mu\mu, e\mu) = 5\%$$

- Lepton + Jets (1 high- P_T lepton, 4 jets (2 b's), large E_T):

$$\text{BR} = 4/9 \quad \text{BR}(e, \mu + \text{jets}) = 30\%$$

- All-hadronic (6 jets) : $\text{BR} = 4/9$

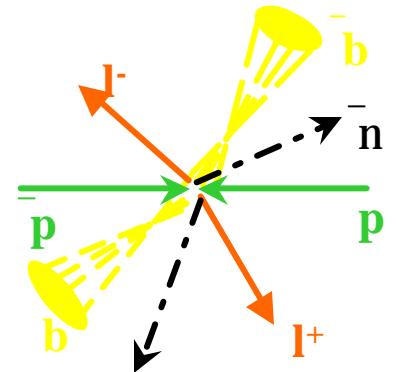
$$\text{BR} = 44\%$$



	Run1(110pb^{-1})	Run2a (2fb^{-1})
N_{tt}	500	14000
$N(\text{sgl top})$	250	7000
$N(t\bar{t} @ l + \cancel{E}_T + 2\text{jets})(\text{dilepton})$	4	150
$N(t\bar{t} @ l + \cancel{E}_T + 3\text{jets})(^31 \text{ b-tag})$	25	1400
$N(t\bar{t} @ l + \cancel{E}_T + 4\text{jets})(2 \text{ b-tags})$	5	600
$N(\text{single } t) (W + 2\text{jets}, 1 \text{ btag})$	3	140

Backgrounds:

WW/WZ, DrellYan ($Z \rightarrow ee, \mu\mu$), $Z \rightarrow \tau\tau$,
and fake leptons in $W+jets$



Selection criteria

- Two high- P_T (20 GeV) opposite charged central leptons (e or μ):

→ Both isolated , ✗ Fakes, Wbb

→ $76 < M_{ee,\mu\mu} < 106$ GeV/c² ✗ Z^0 's

- Large Missing Energy from Neutrinos

→ $E_T > 25$ GeV ✗ $Z \rightarrow \tau\tau$

→ $\Delta\phi(E_T, \text{lepton or jet}) > 20^\circ$ or $E_T > 50$ GeV
✗ DrellYan, $Z \rightarrow \tau\tau$

- Two b - quark jets ✗ WW/WZ

→ at least 2 jets with raw $E_T > 10$ GeV, $||\eta_{\text{detector}}| < 2.0$

→ b tagging will come with more statistics.

- Large Total Energy

→ $H_T > 200$ GeV (Σ of E_T , l 's and jets)

Disadvantages low yield

Advantages high S/B~ 8

$S(t\bar{t})$ dilepton cross section ($L=72 \text{ pb}^{-1}$)

- WW/WZ, $Z \rightarrow \tau\tau$ rejection from MC.
- DY rejection from data in Z window → extrapolation MC varying Q^2
- Fakes estimated from QCD data

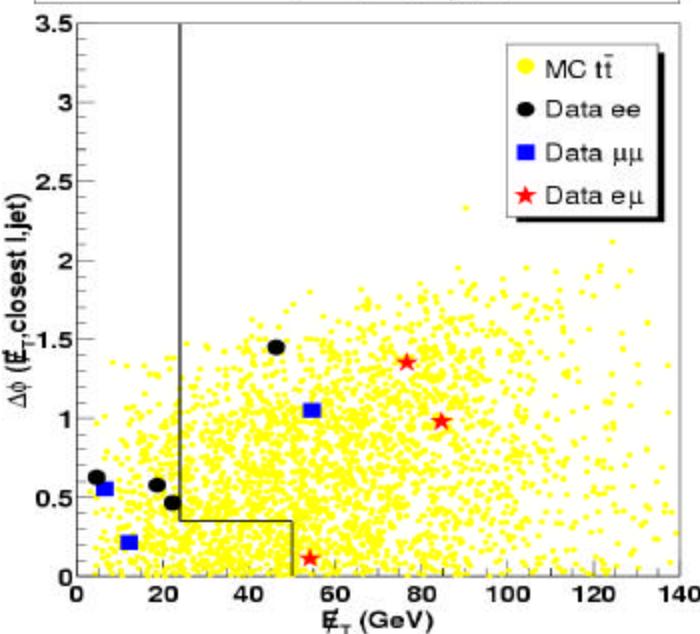
Source	ee	nm	em	II
Background	0.103 ± 0.056	0.093 ± 0.054	0.100 ± 0.037	0.30 ± 0.12
$t\bar{t} \rightarrow l\nu b\bar{b}$	0.47 ± 0.05	0.59 ± 0.07	1.44 ± 0.16	2.5 ± 0.3
SM expectation	0.57 ± 0.08	0.68 ± 0.09	1.5 ± 0.2	2.8 ± 0.3
Data	1	1	3	5

$$S_{t\bar{t}} = 13.2 \pm 5.9_{\text{stat}} \pm 1.5_{\text{sys}} \pm 0.8_{\text{lum}} \text{ pb}$$

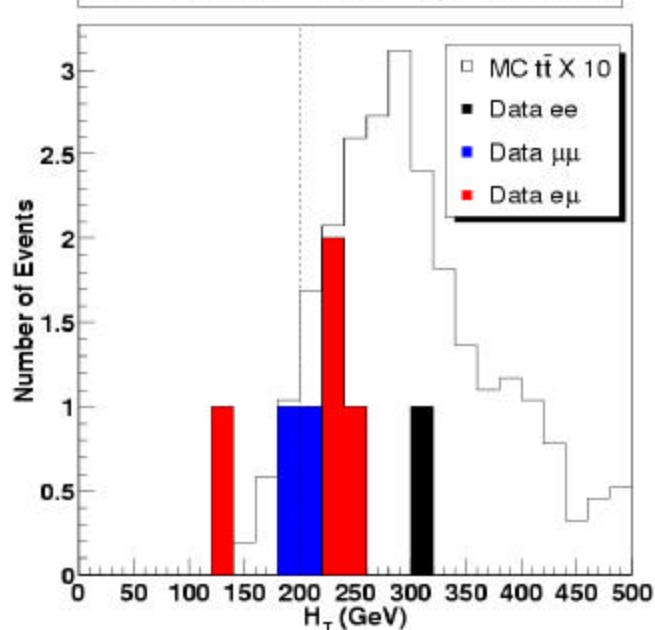
NLO @ $\tilde{\sigma}=1.96 \text{ TeV}$ for $M_{\text{top}} = 175 \text{ GeV}$: $6.70^{+0.71}_{-0.88} \text{ pb}$

[hep-ph/0303085 \(ML Mangano et al\)](https://arxiv.org/abs/hep-ph/0303085)

CDF Run II Preliminary - $\Delta\phi$ vs E_T , $N_{\text{jets}} \geq 2$, After all cuts



CDF Run II Preliminary - H_T Distribution



top dilepton candidate

tt dilepton candidate:

Nov 26 2002 run:

154654 event: 7344016

m^+m^- (CMUP-CMX) +
2 jets

$$p_T(m_1) = 57 \text{ GeV}/c^2$$

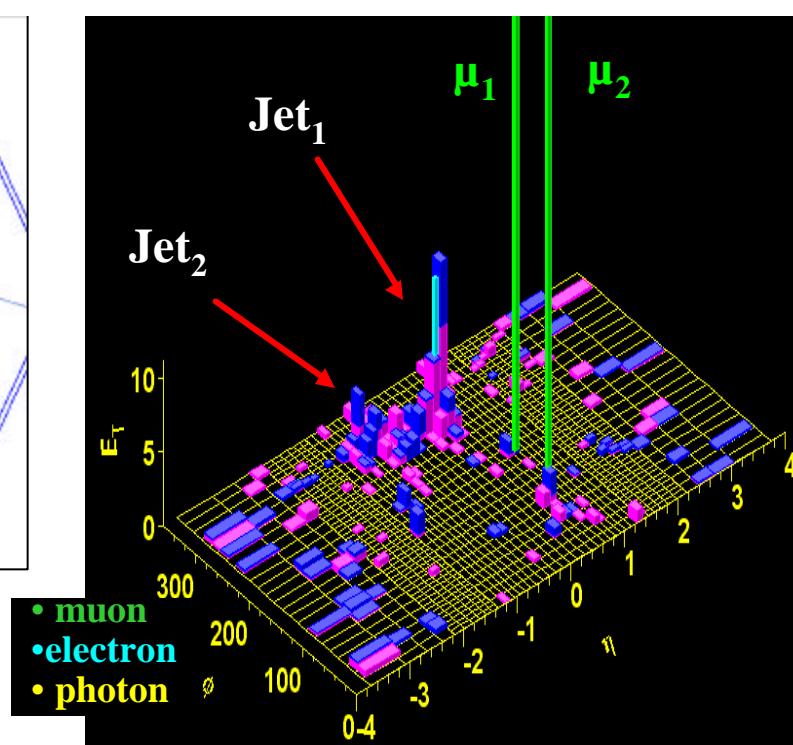
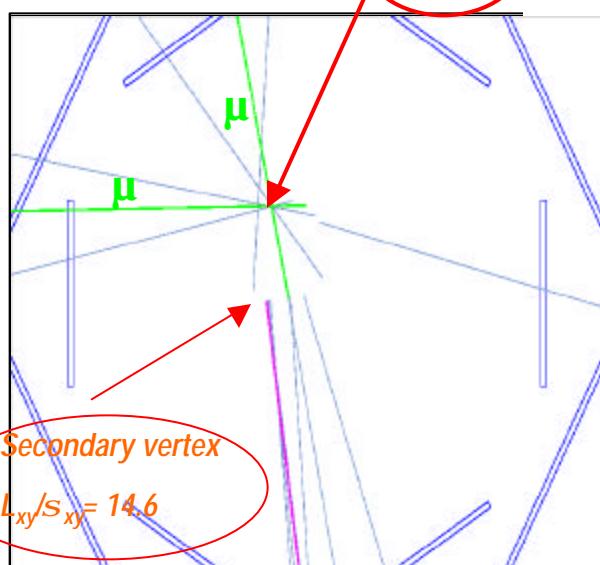
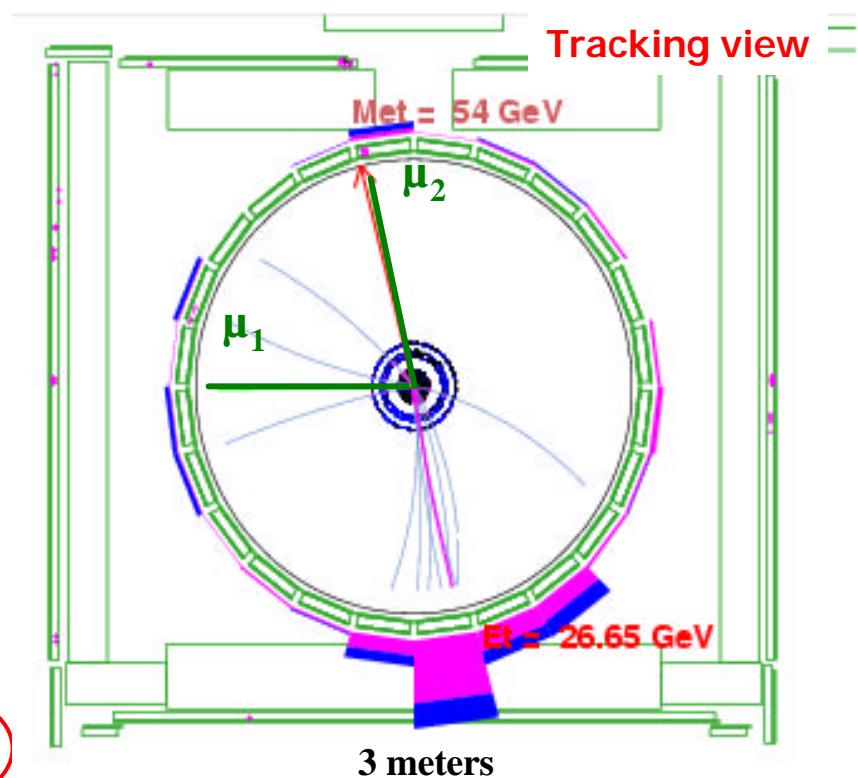
$$p_T(m_2) = 53 \text{ GeV}/c^2$$

$$M_{mm} = 69 \text{ GeV}/c$$

$$E_T^j = 32, 15 \text{ GeV}$$

$$E_T = 54 \text{ GeV}$$

$$H_T = 212 \text{ GeV}$$



Lego view



$s(t\bar{t})$ dilepton cross section

- Two channels so far: $\mu\mu$ ($L=42.6 \text{ pb}^{-1}$) and $e\mu$ ($L=33.0 \text{ pb}^{-1}$)
- Analogous selection criteria than CDF, except :
 - Z veto not applied when large \not{E}_T (to recover acceptance)
- Backgrounds:
 - Z/DY $\rightarrow \mu\mu, e\mu$ QCD HF from data
 - Z $\rightarrow \tau\tau, WW$ from MC

Source	$e\mu$	$\mu\mu$	ll
Background	0.07 ± 0.01	0.60 ± 0.01	0.67 ± 0.01
$t\bar{t} \rightarrow l l v b \bar{b}$	0.50 ± 0.01	0.30 ± 0.04	0.8 ± 0.04
SM expectation	0.57 ± 0.01	0.9 ± 0.04	1.47 ± 0.04
Data	1	2	3

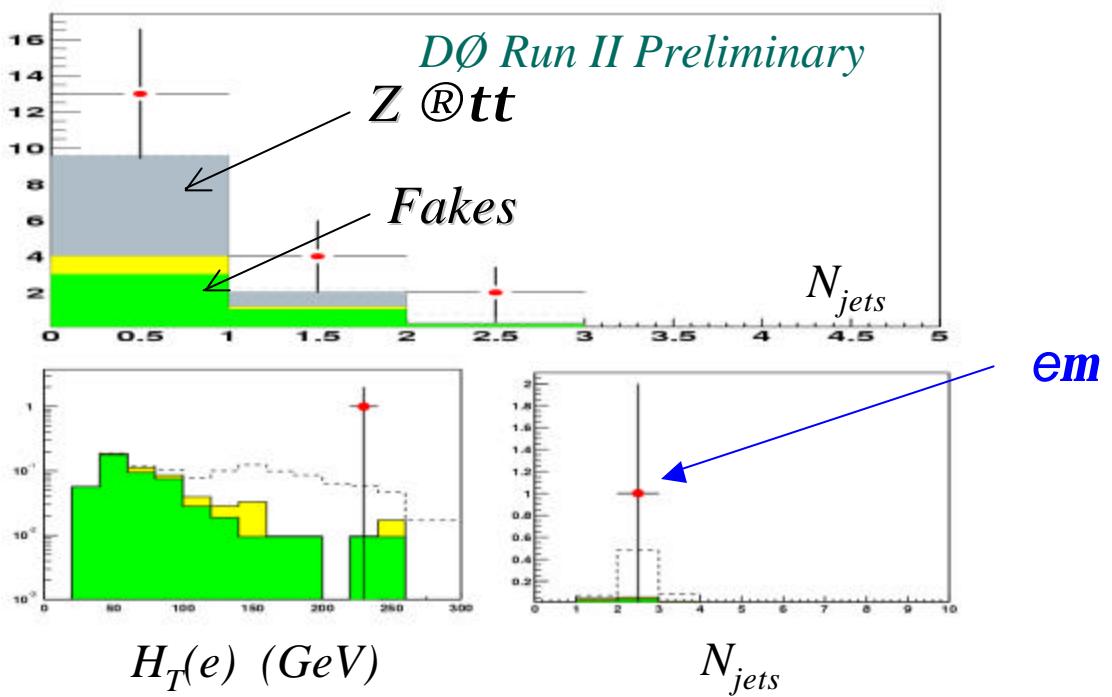
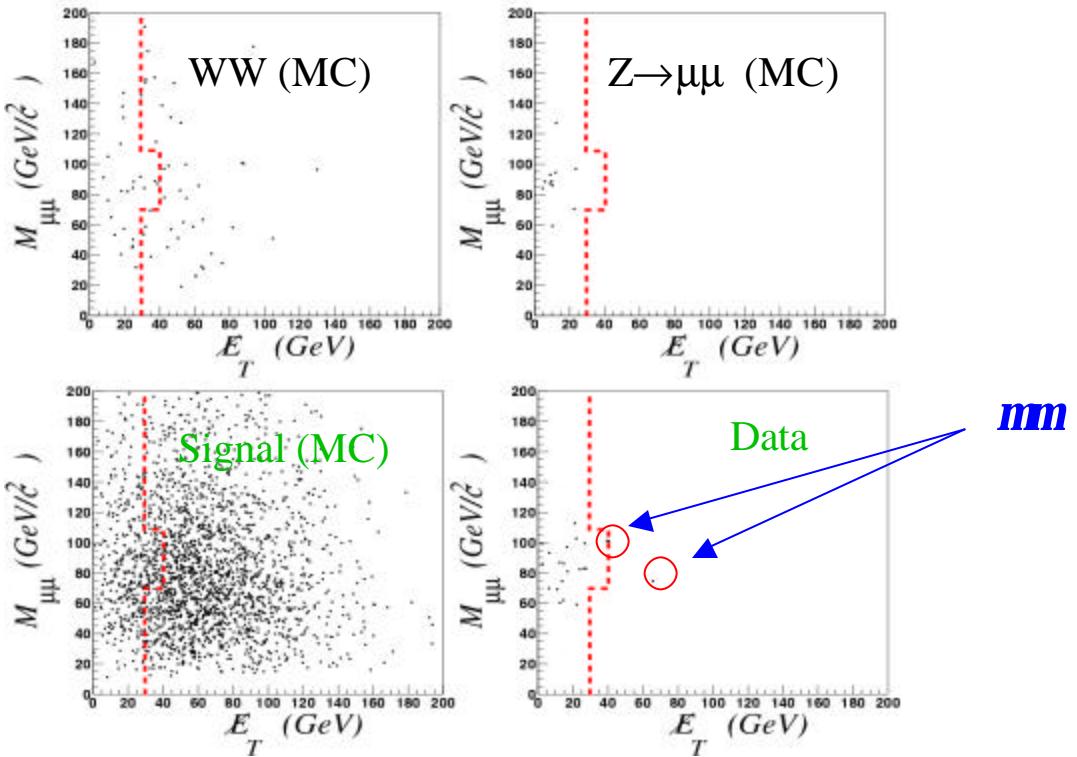
$$s = 18.8^{+20.4}_{-12.0} \text{ (stat)} \quad {}^{+7.9}_{-2.9} \text{ (syst)} \pm 1.9 \text{ (lumi)} \text{ pb}$$

NLO @ $\tilde{0}s=1.96 \text{ TeV}$ for $M_{\text{top}} = 175 \text{ GeV}$: $6.70^{+0.71}_{-0.88} \text{ pb}$
hep-ph/0303085(ML Mangano et al)



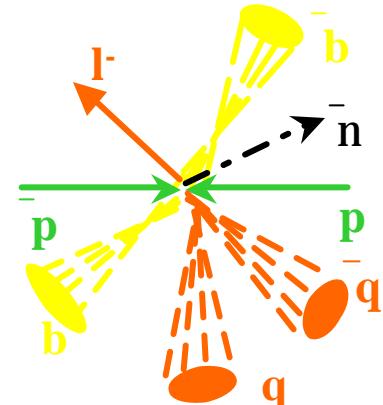
top dilepton kinematics

D \emptyset Run II Preliminary



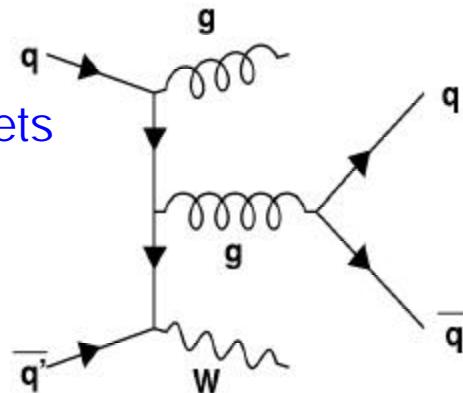
Experimental signature:

- Exactly one high pt lepton with $p_T > 20$ GeV
- Large $E_T > 20$ GeV
- Large jet multiplicity: Jets $E_T > 15$ GeV & $|\eta| < 2.0$
- Cosmic ray , electron conversion removal.
- Top dilepton veto, Z boson veto.



Backgrounds

- W/Z+heavy flavour ($g \rightarrow bb, cc$)
- Mistags from light quarks and gluon jets
- Non W background (fake lepton),
- diboson, Drell-Yan, single top (small)



D0
From kinematics

³ 4 jets to measure σ_{tt}

$S(t\bar{t})$

CDF
Tagging b-jets with displaced vertices

³ 3 jets to measure $\sigma_{tt, b} \geq 1$ b-tag
• Better S/B: Only 2% W+jets expected to have b quarks

D0:

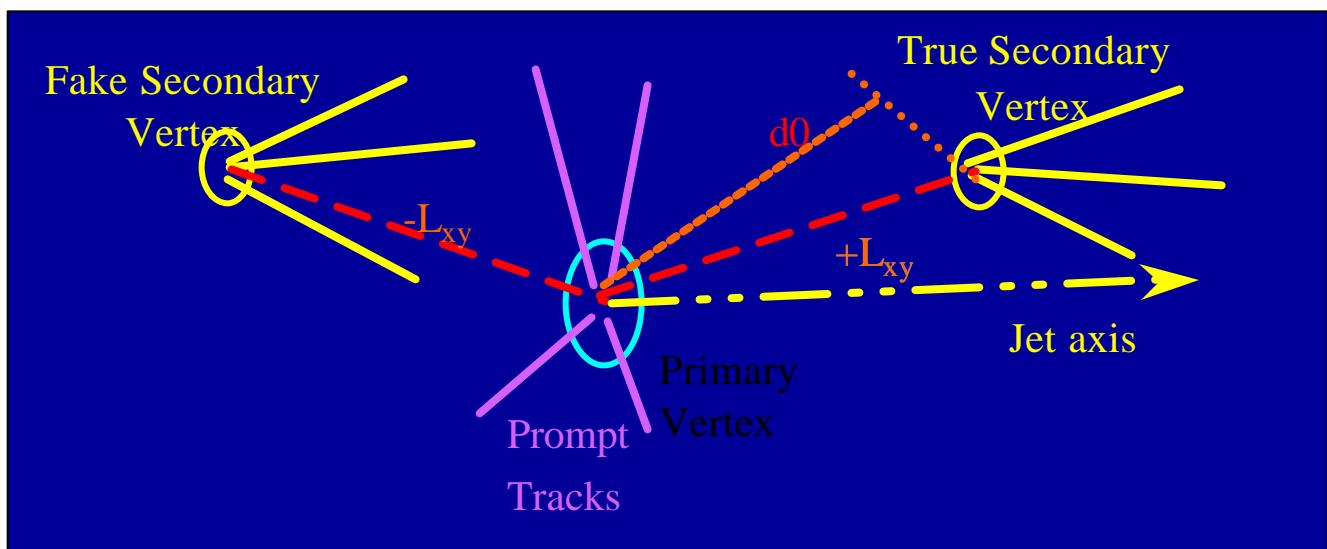
Tagging b-jets with Soft Muon Tags

³ 3 jets to measure $\sigma_{tt, b} \geq 1$ SMT-tag

- Signature of a b decay is a displaced vertex:
 - Long lifetime of b/c hadrons ($c\tau \sim 450 \mu\text{m}, 1 \text{ ps}$)
 - B hadrons travel up to $L_{xy} \sim 3\text{mm}$ before decay with large charged track multiplicity.

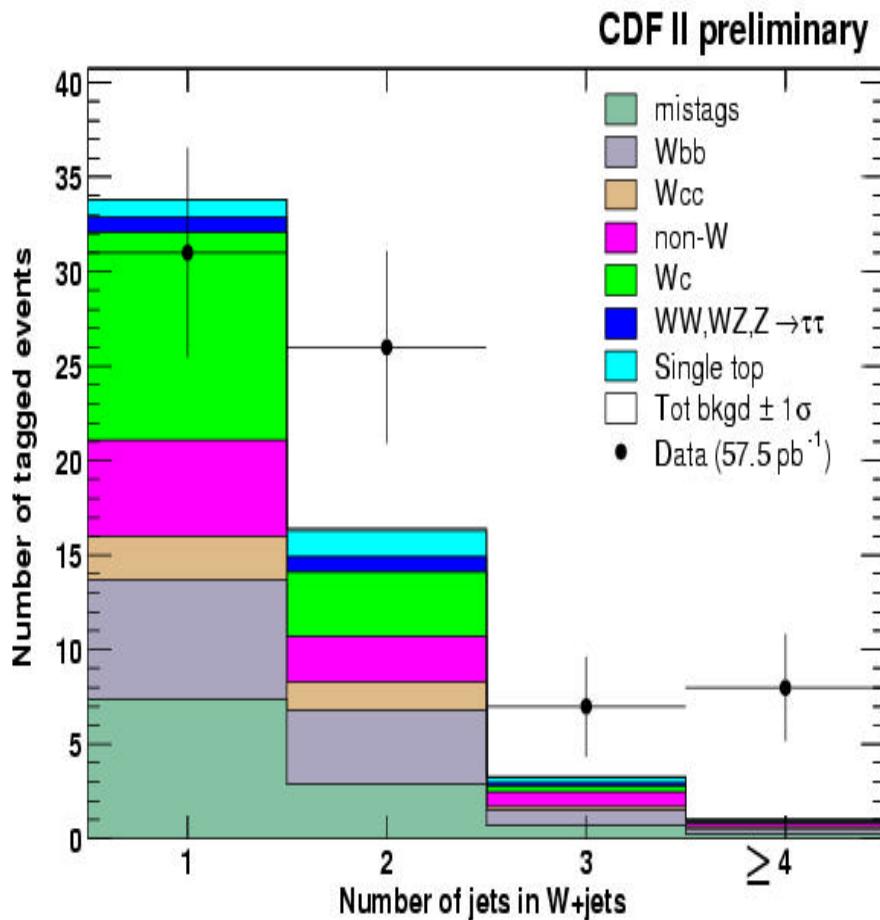
- Algorithm:

- Look for displaced vertices: all combination of at least 2 tracks
- Jet is tagged as b-jet if $L_{xy}/\sigma_{xy} > 3$ (typical $\sigma_{xy} \sim 150 \mu\text{m}$)



- Efficiency of b-tagging a $t\bar{t}$ event:
 $e(\text{event tag}) = 45 \pm 1 \pm 5 \%$

I+jets channel BACKGROUNDS



Mistags:

a fake rate matrix(E_t, η) from inclusive jet data per jet :

$$\text{neg-rate} = \#\text{tagged jets with } L_{xy} < 0 / \#\text{taggable jets}$$

→ is applied to every single taggeable jet found in W+jets sample

W_{bb}, W_{cc}, W_c : [Event Fraction] \times [Efficiency] \times [N_{W+jets}]

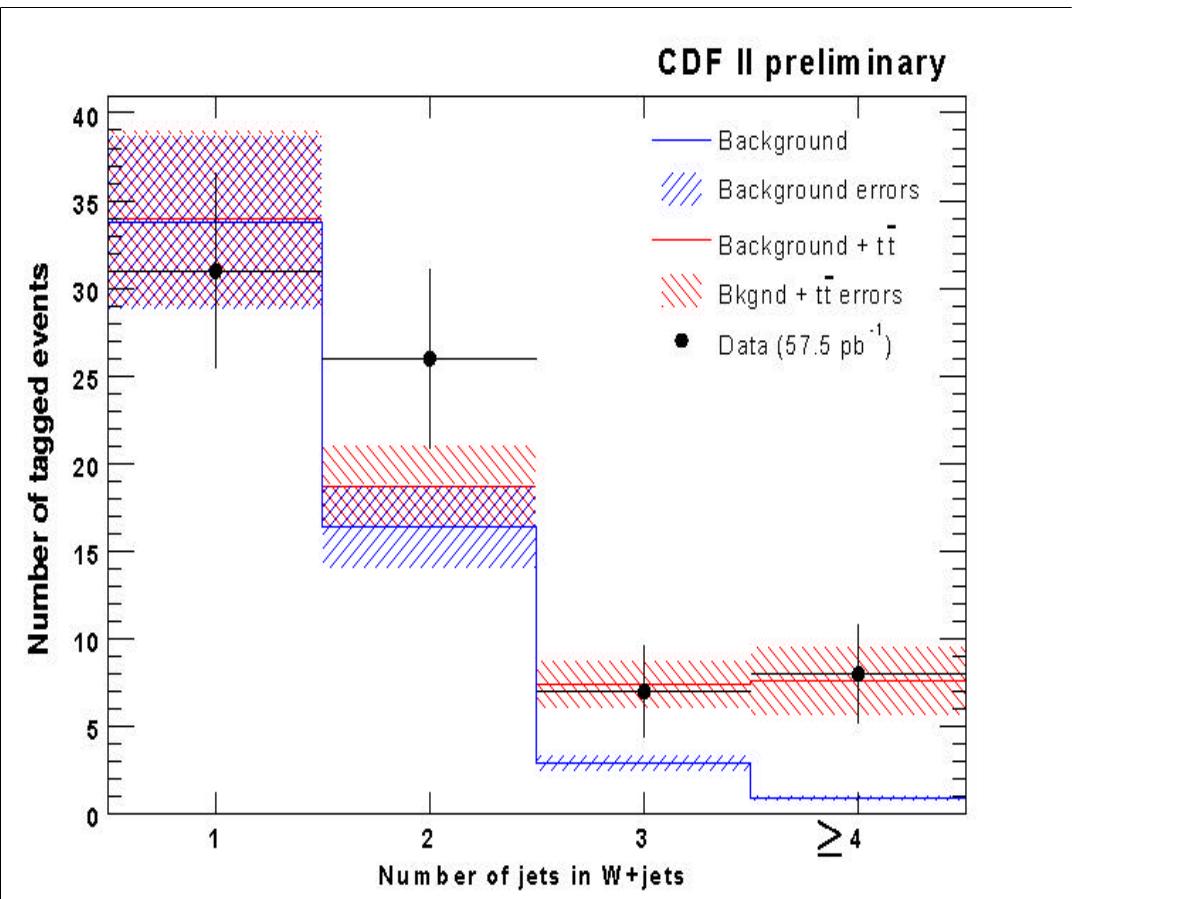
Event Fraction: heavy flavor fraction in W+jets events from Run 1

Efficiency: b-tagging rate from Run 2 MC, Scale Factor applied

N_{W+jets} in Run 2 data.

Non-W: from data, isolation vs Et method

WW,WZ,Z->ττ,Single top from MC



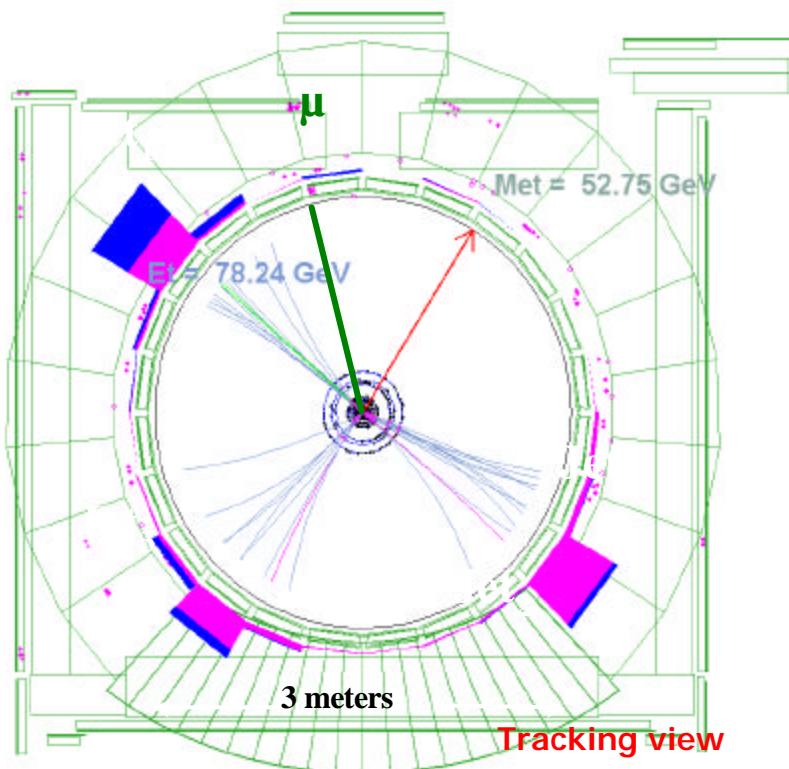
→ Signal

Source	$W+1jet$	$W+2jets$	$W+3jets$	$W+4jets$
Background	33.8 ± 5.0	16.4 ± 2.4	2.88 ± 0.05	0.87 ± 0.2
SM Bkgnd + $t\bar{t}$	34.0 ± 5.0	18.65 ± 2.4	7.35 ± 1.4	7.62 ± 2.0
Events before tagging	4913	768	99	26
Events after tagging	31	26	7	8

$$S_{tt} = 5.3 \pm 1.9_{\text{stat}} \pm 0.8_{\text{sys}} \pm 0.3_{\text{lum}} \text{ pb}$$

NLO @ $\hat{s}=1.96 \text{ TeV}$ for $M_{\text{top}} = 175 \text{ GeV}$: $6.70^{+0.71}_{-0.88} \text{ pb}$

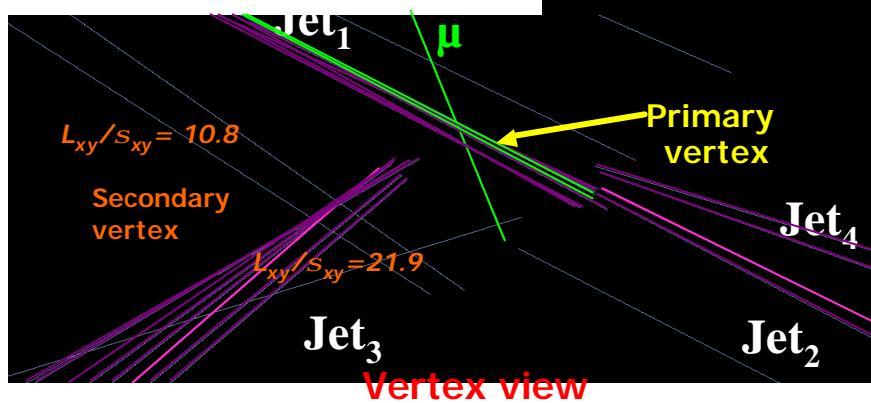
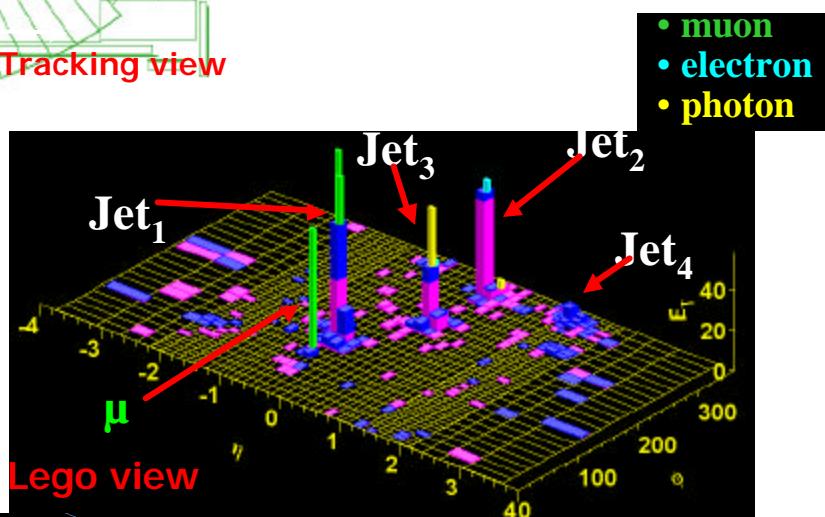
top lepton plus jets candidate



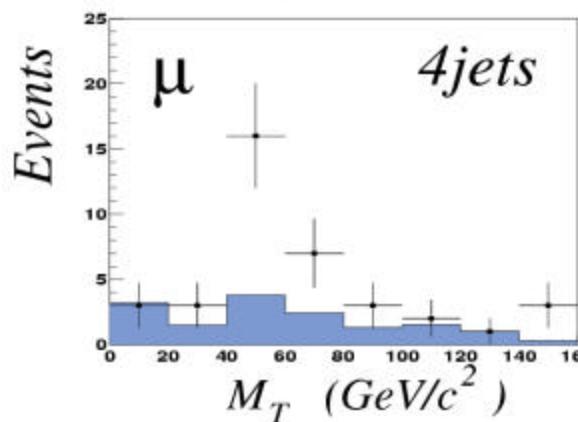
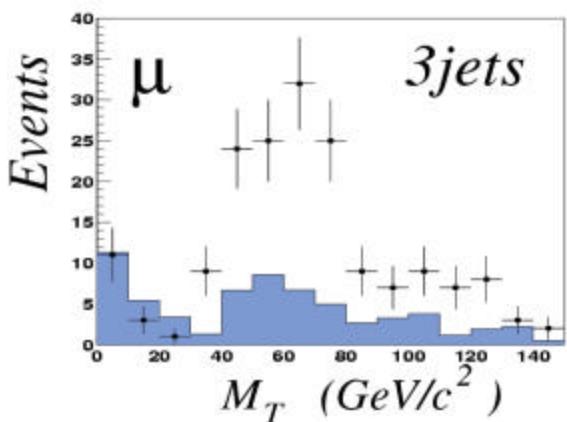
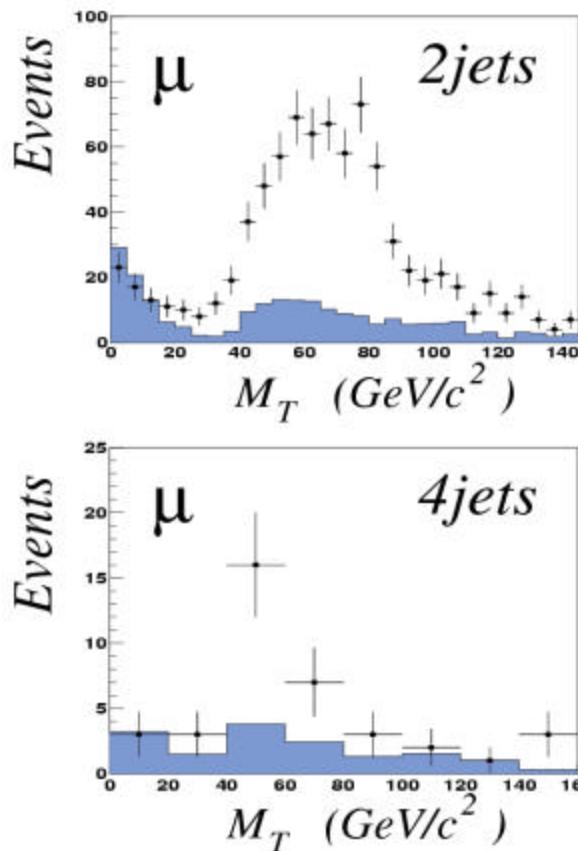
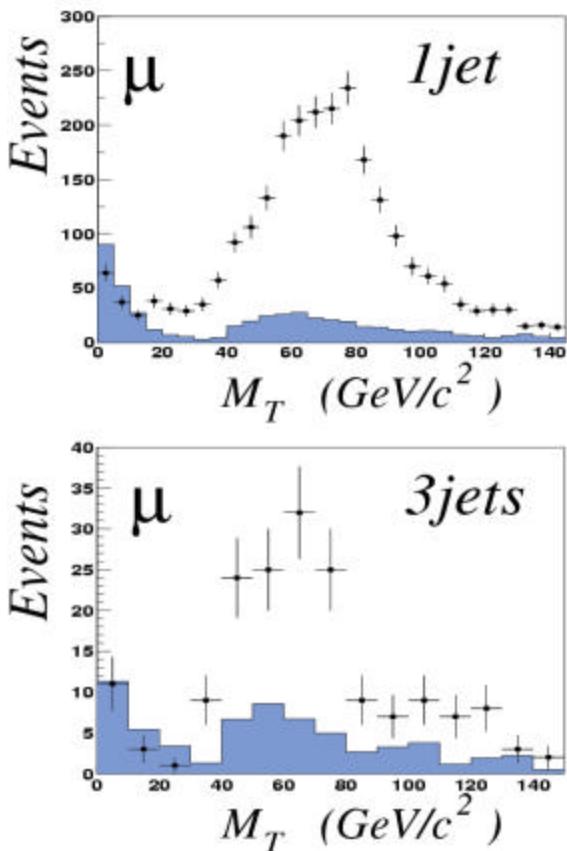
tt l+jet candidate: Nov 02 2002
run: 153693 event: 799494
 μ (CMUP) + 4 jets

$p_T(m) = 54.4 \text{ GeV}/c^2$
 $E_T^j = 96.7, 65.8, 54.8, 33.8 \text{ GeV}$
 $E_T = 40.8 \text{ GeV}$

- muon
- electron
- hadron

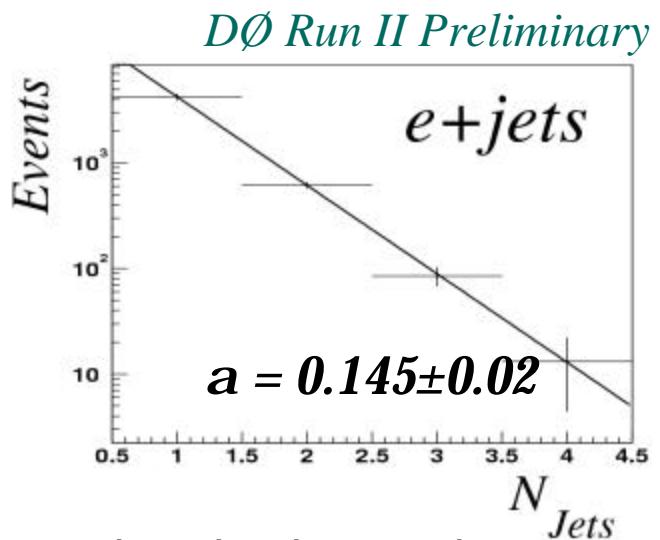


- ◆ LUMINOSITY: $e+jets$ 49.5 pb^{-1} $\mu+jets$ 40.0 pb^{-1}
- ◆ METHODOLOGY:
 - ◆ Preselection: sample enriched with W :
 - ◆ A loose lepton, \not{E}_T and soft muon veto
 - ◆ Background nature:
 - ◆ $W+jets$ and QCD multi-jet
 - ◆ $\mu+jets$ ® real μ from B decays
 - ◆ $e+jets$ ® jets faking electron ID (π^0 and γ QCD Compton)

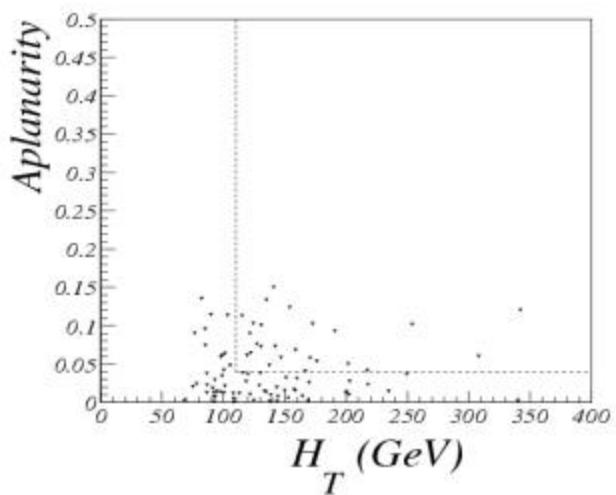
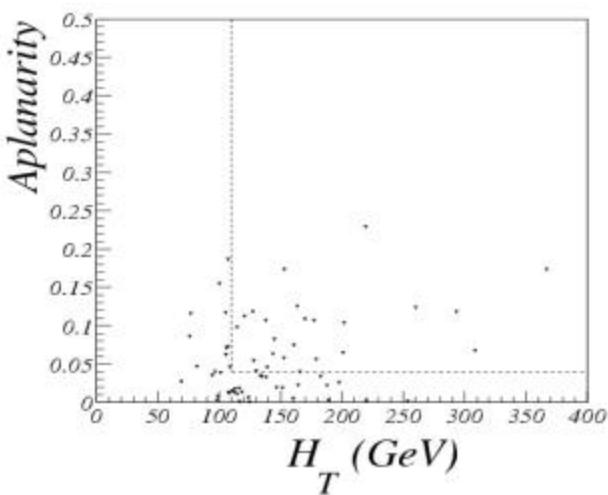


- Berends scaling method to estimate W background for $N_{jets} \geq 4$:

$$a \equiv \frac{s(W + (n+1)_{jets})}{s(W + n_{jets})}$$



- Final Topological selection to reduce background
 - $H_T > 180\text{GeV}$ ($e+jets$)
 - H_T (with W recoil jets) $> 220\text{GeV}$ ($\mu+jets$)
 - Aplanarity > 0.065



Channel	N_W	N_{QCD}	Bkg. Tot.	Signal	N_{obs}
$e+jets$	1.3 ± 0.5	1.4 ± 0.4	2.7 ± 0.6	1.8	4
$\mu+jets$	2.1 ± 0.9	0.6 ± 0.4	2.7 ± 1.1	2.4	4

• **PRESELECTION:** same as l+jets kinematic analysis

• **TOPOLOGICAL SELECTION:** prior to SMT tag

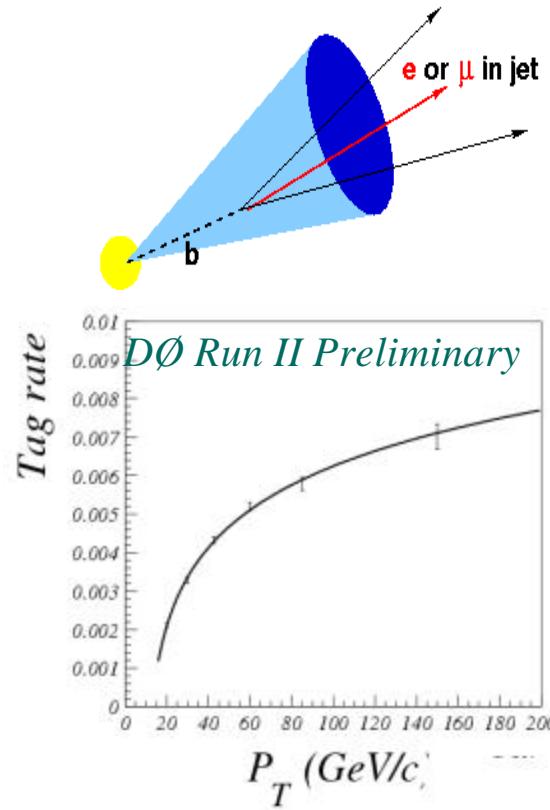
- $N_{\text{jets}} \geq 3$
- $H_T > 110 \text{ GeV} (\text{e}/\mu + \text{jets})$
- Aplanarity > 0.04

• **SMT** is applied

- To increase S/B
- To identify e or μ from decays: $b \rightarrow lvc$, $b \rightarrow c \rightarrow lvs$

• **BACKGROUNDS:** from data

- QCD + multijets
- $W + \text{jets}$



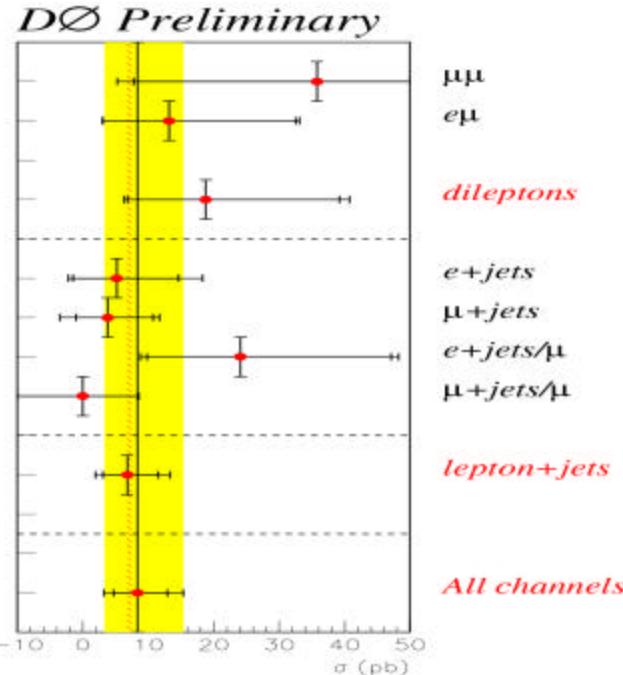
Channel	Bkg. Tot.	Sig.	N_{obs}
$e + \text{jets}$	0.2 ± 0.1	0.5	2
$m + \text{jets}$	0.6 ± 0.3	0.4	0

S_{tt} lepton plus jets (kinematic and SMT combined)

$$s = 6.8^{+4.7}_{-3.7} \text{ (stat)} \quad {}^{+4.5}_{-3.1} \text{ (syst)} \pm 0.7 \text{ (lumi)} \text{ pb}$$

D0 *Combining
all channels:*

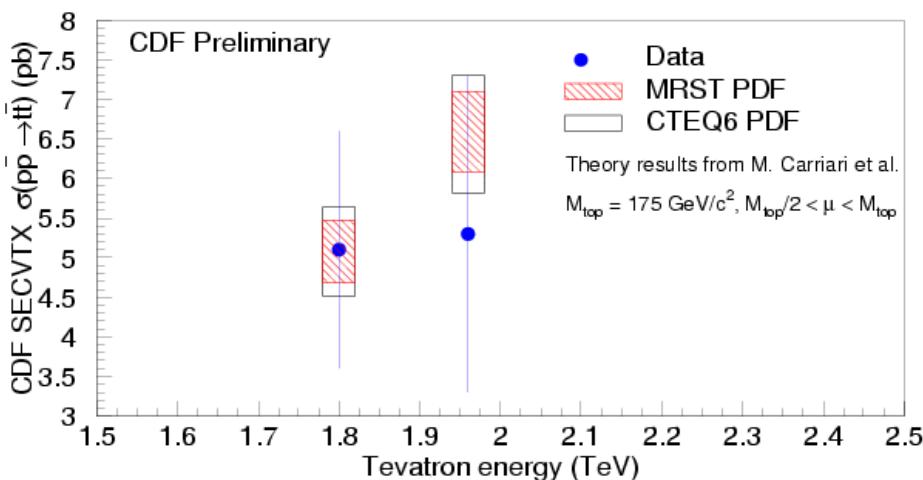
$$S_{t\bar{t}} = 8.4^{+4.5}_{-3.7} \text{ (stat)}^{+5.3}_{-3.5} \text{ (syst)} \pm 0.8 \text{ (lumi) pb}$$



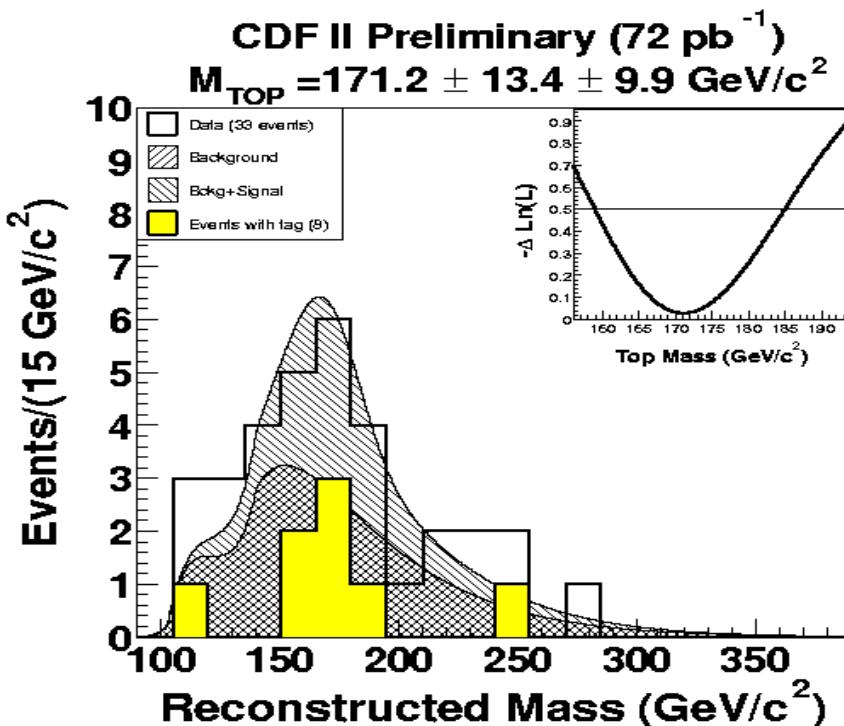
CDF *Dileptons*

$$\sigma_{t\bar{t}} = 13.2 \pm 5.9_{\text{stat}} \pm 1.5_{\text{sys}} \pm 0.8_{\text{lum}} \text{ pb}$$

Lepton plus jets $\sigma_{t\bar{t}} = 5.3 \pm 1.9_{\text{stat}} \pm 0.8_{\text{sys}} \pm 0.3_{\text{lum}} \text{ pb}$



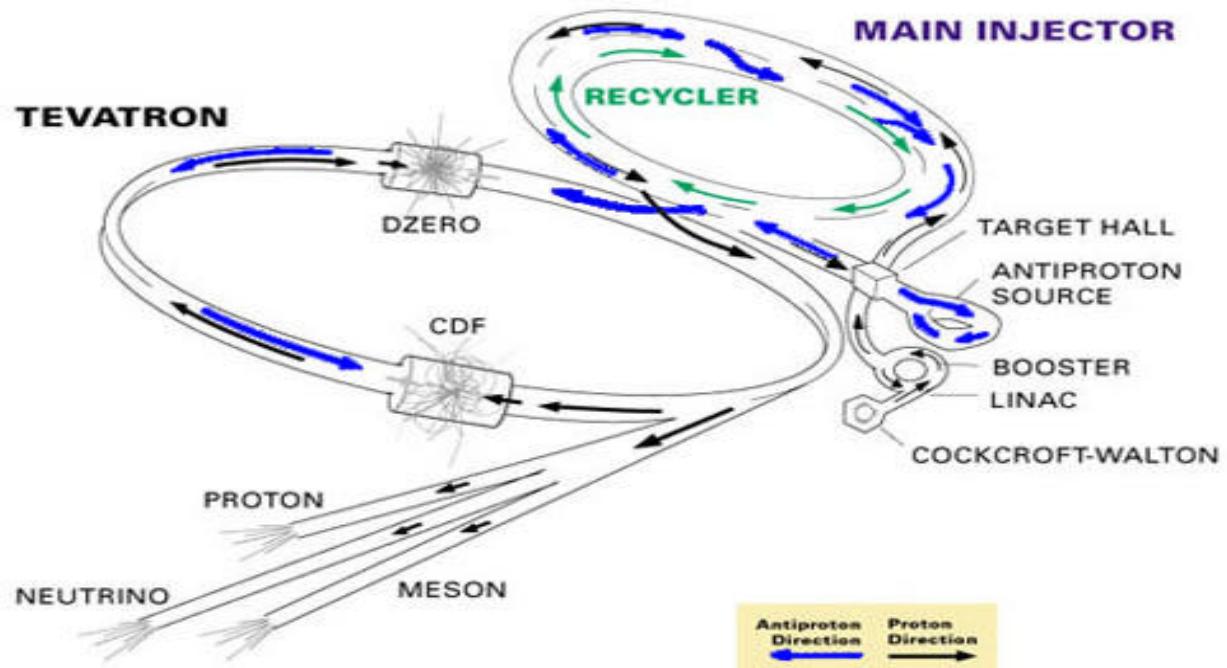
- We have **reestablished** the presence of the **top quark** in Run 2.
- The measured cross sections in *dilepton* and *lepton plus jets* channels are **in agreement with** the **SM expectation**
- The selected $t\bar{t}$ events show a **mass** compatible with the run 1 measurement:



Please tune in to the talk
Top quark mass measurement and decay properties at the Tevatron
by R.Zitoun today at 9:10 am



Suport material

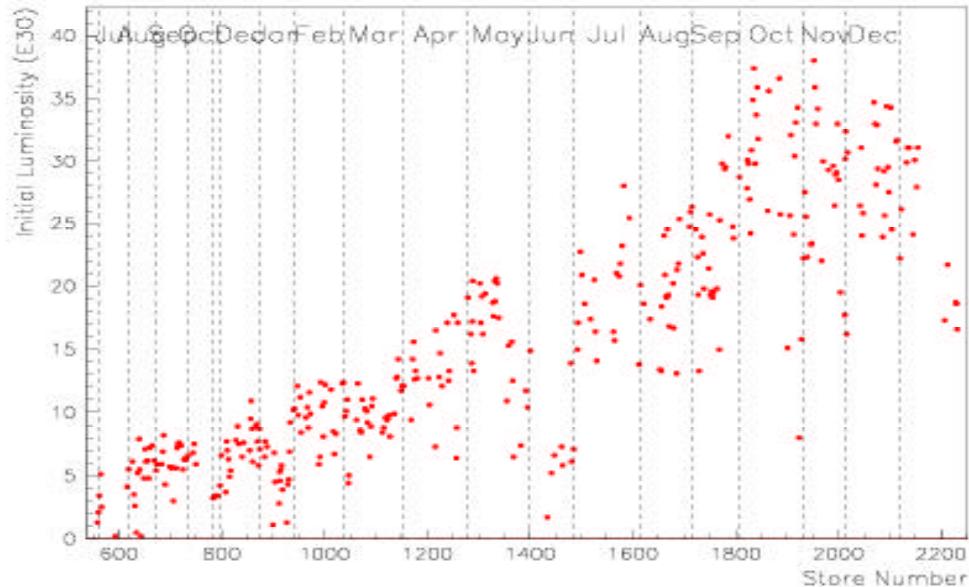


Run II: proton-antiproton collisions at $\sqrt{s}=1.96$ TeV



- Instantaneous Luminosity ($10^{30} \text{ cm}^{-2} \text{ s}^{-1}$)

Tevatron Run 2a goal is $5\text{-}8 \times 10^{31}$



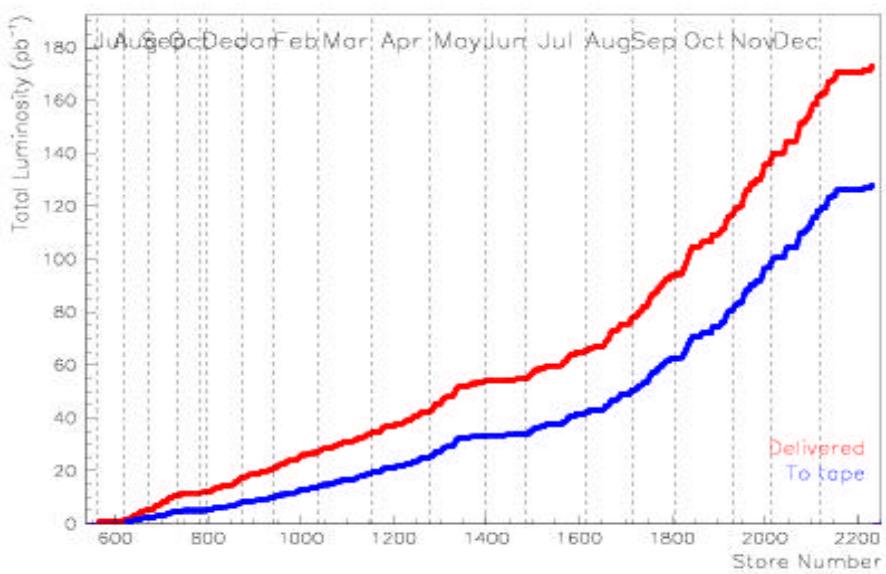
- Integrated Luminosity (pb^{-1})

~ 170 pb^{-1} delivered

~ 130 pb^{-1} on tape

(by CDF)

Tevatron Run 2a goal is 2 fb^{-1}



Analysis-quality data accumulated by March 2003

- CDF 72.0 pb^{-1} (58.1 pb^{-1} with silicon)
- D0 $30\text{-}50 \text{ pb}^{-1}$

Detector upgrades for Run 2 have been extensive.

CDF:

- Tracking:

 - Expanded silicon coverage.

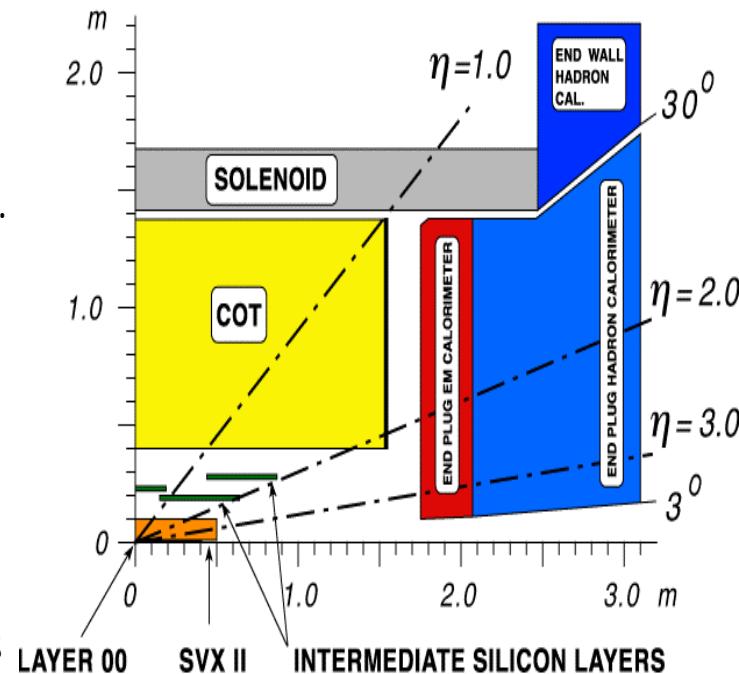
 - New drift chamber (COT)

- Extended lepton-ID: $|\eta| > 1$

 - End Plug calorimeter

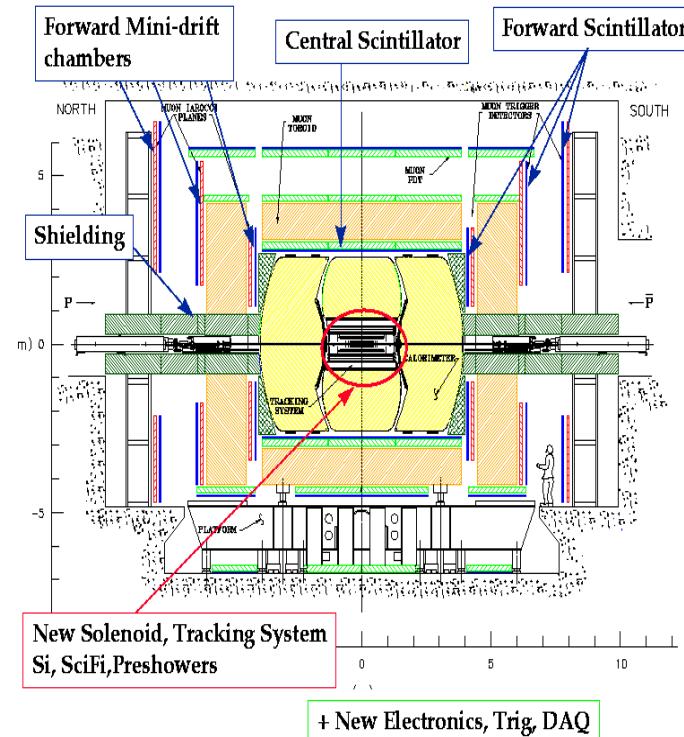
 - Expanded Muon coverage

- Trigger: drift chamber tracks @ L1 and silicon Tracks @ L2.



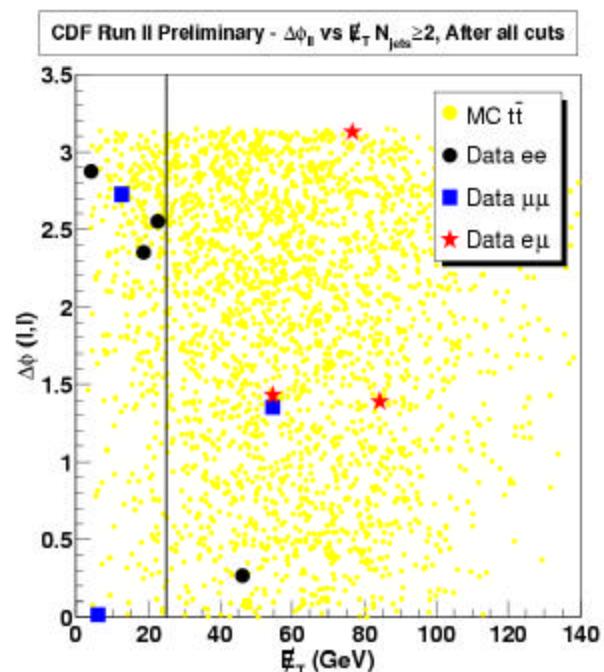
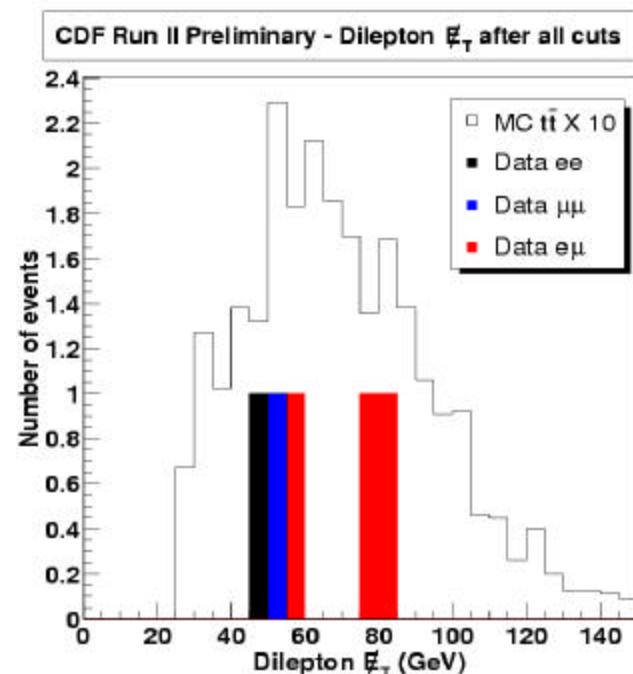
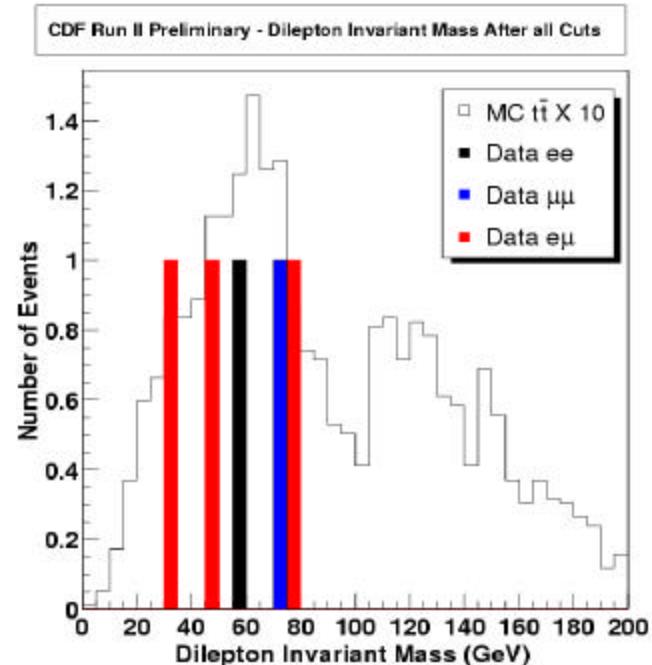
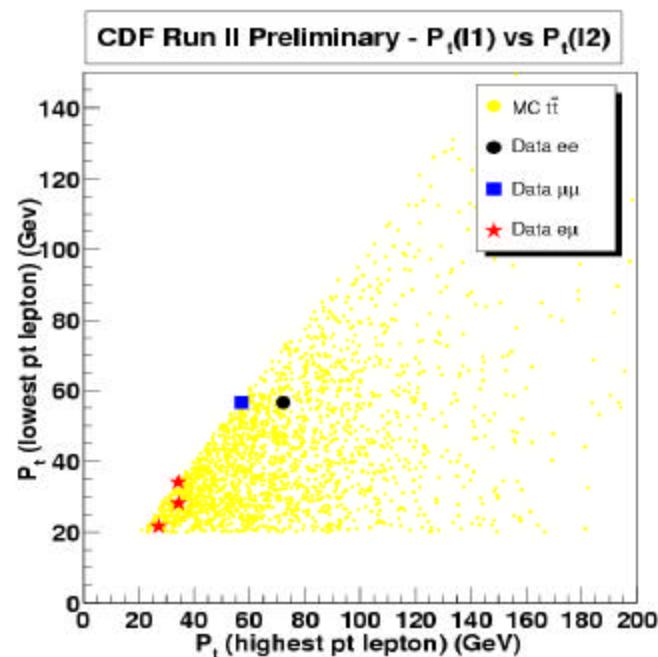
D0

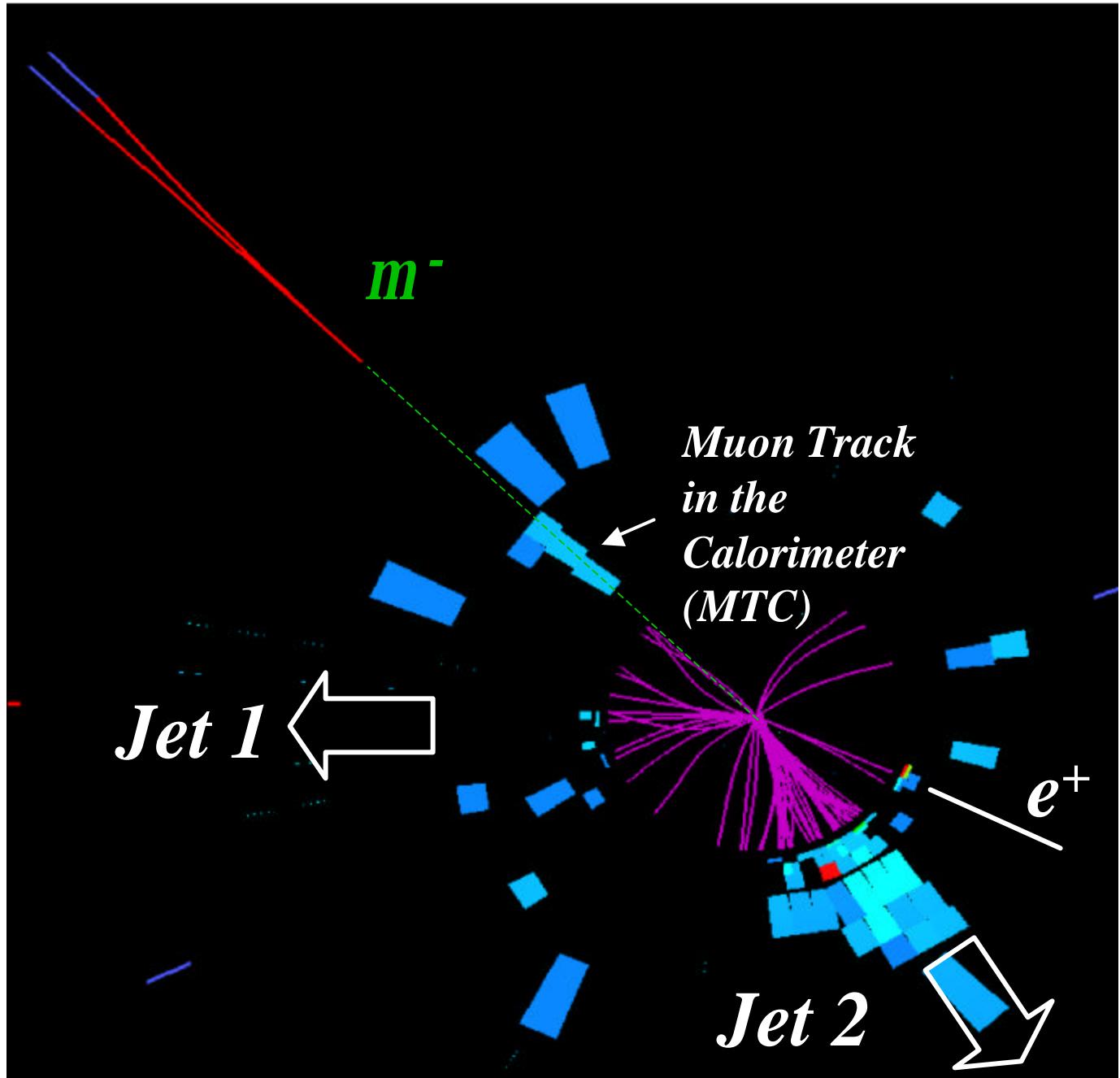
- New Inner tracking (silicon tracker, fiber tracker, preshower) with 2T superconducting solenoid
- Excellent calorimetry with faster readout.
- Upgraded μ system for better μ -ID

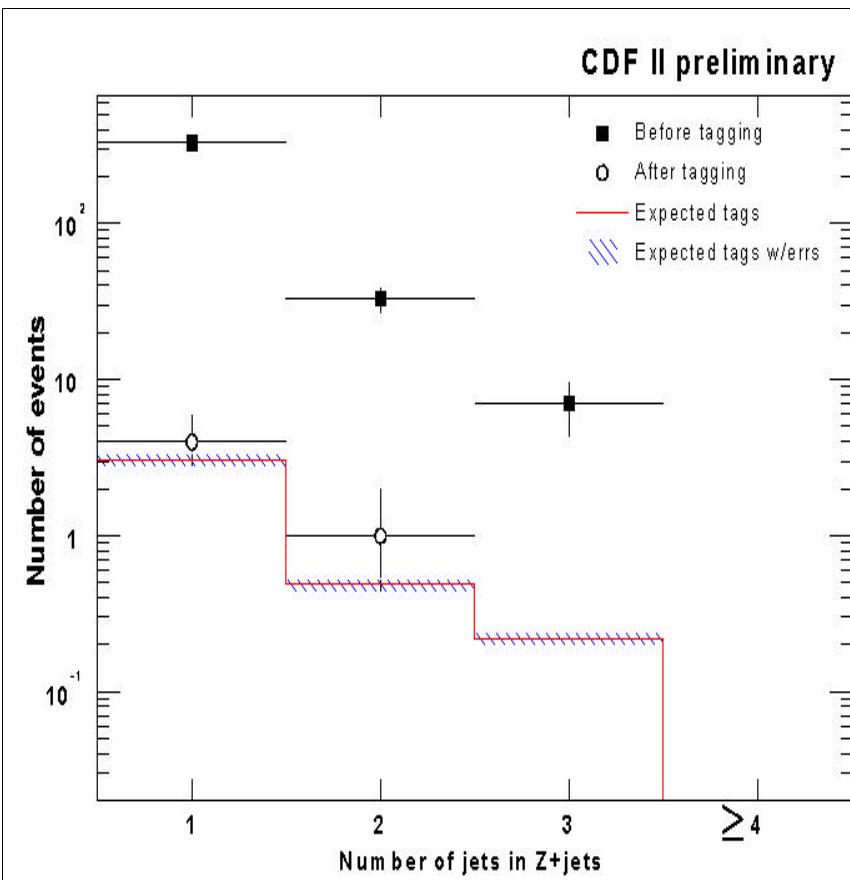


top dilepton kinematics

The kinematic properties of all 5 tt candidates in comparison with MC Herwig tt sample.



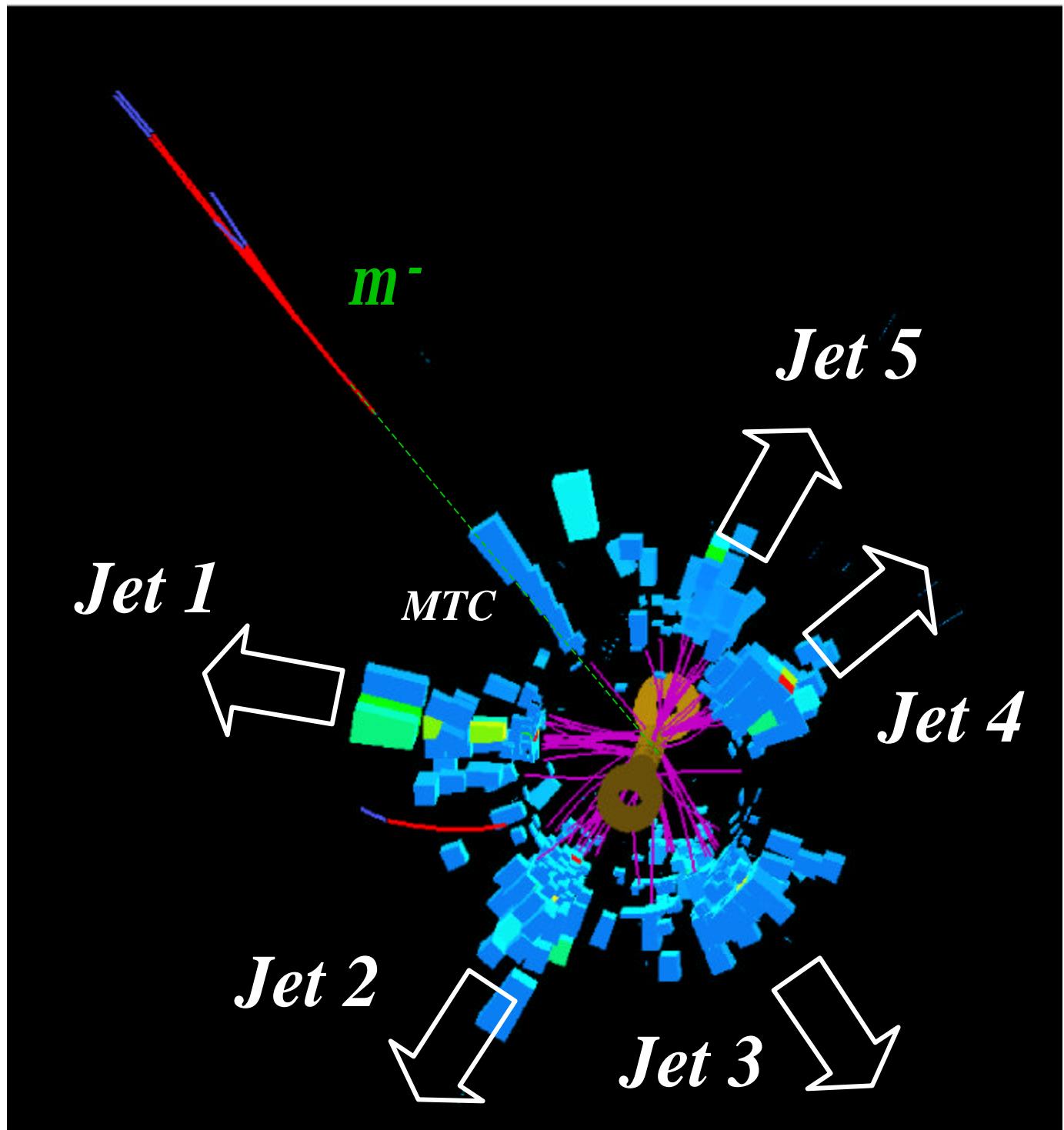




- Observed b-tags in $Z+jets$ data (5)
- the expected (+)b-tags applying **fake rate matrix** to the same sample (3.7 ± 0.4)

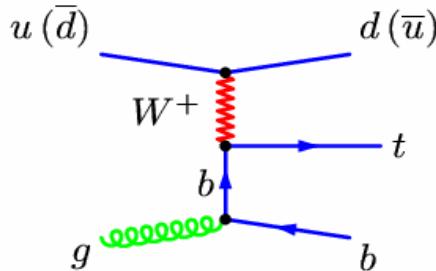


top lepton plus jets candidate



$t\bar{t}$ pair: strong interaction \leftrightarrow single top: electroweak Wtb vertex

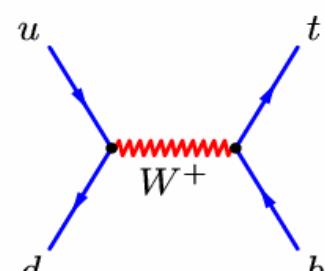
**t-channel
(Wg-Fusion)**



$$2.44 \pm 0.12 \text{ pb}$$

Steltzer, et al. '98

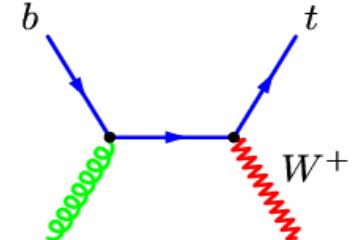
s-channel (W^*)



$$0.88 \pm 0.12 \text{ pb}$$

Smith/Willenbrock '96

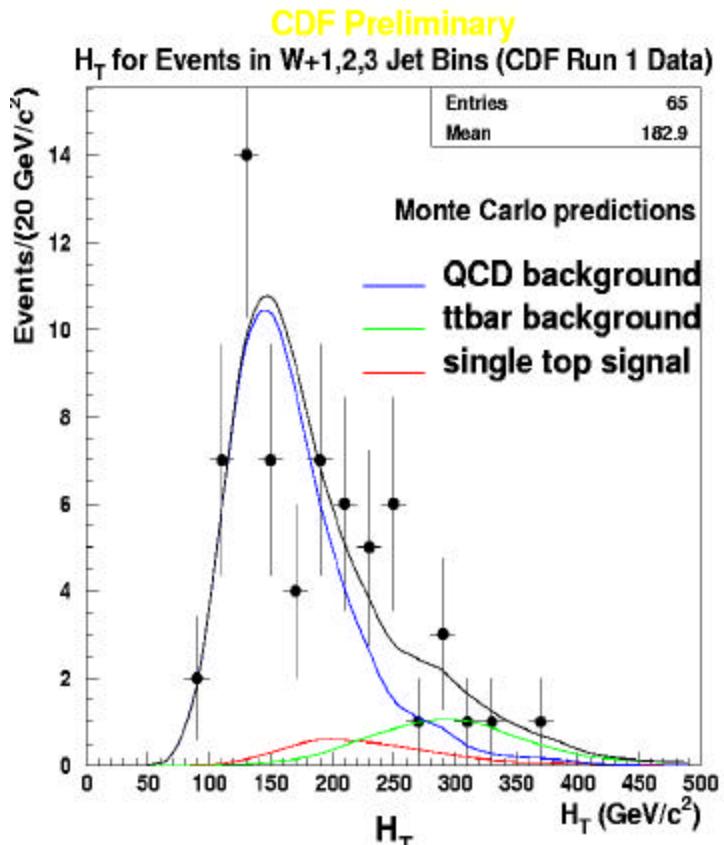
**associated
production**



$$S < 0.1 \text{ pb}$$

Tait '99

- Not observed in Run1:
- CDF combined search: $Wg + W^*$
maximum likelihood fit to H_T distribution
 $\sigma(Wg + W^*) < 14 \text{ pb}$
at 95% C.L.
 $\sigma(Wg) < 13 \text{ pb}$
 $\sigma(W^*) < 22 \text{ pb}$
 Phys. Rev. D. 65, 091102 (2002).



- D0 NN search separated search: $\sigma(Wg) < 22 \text{ pb}$, $\sigma(W^*) < 17 \text{ pb}$
at 95% C.L. Phys. Lett. B 517, 282 (2001)